Simulation of Showers with Geant4

CHEF2013, 22-25 April 2013, Paris

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U.S. DEPARTMENT OF ENERGY
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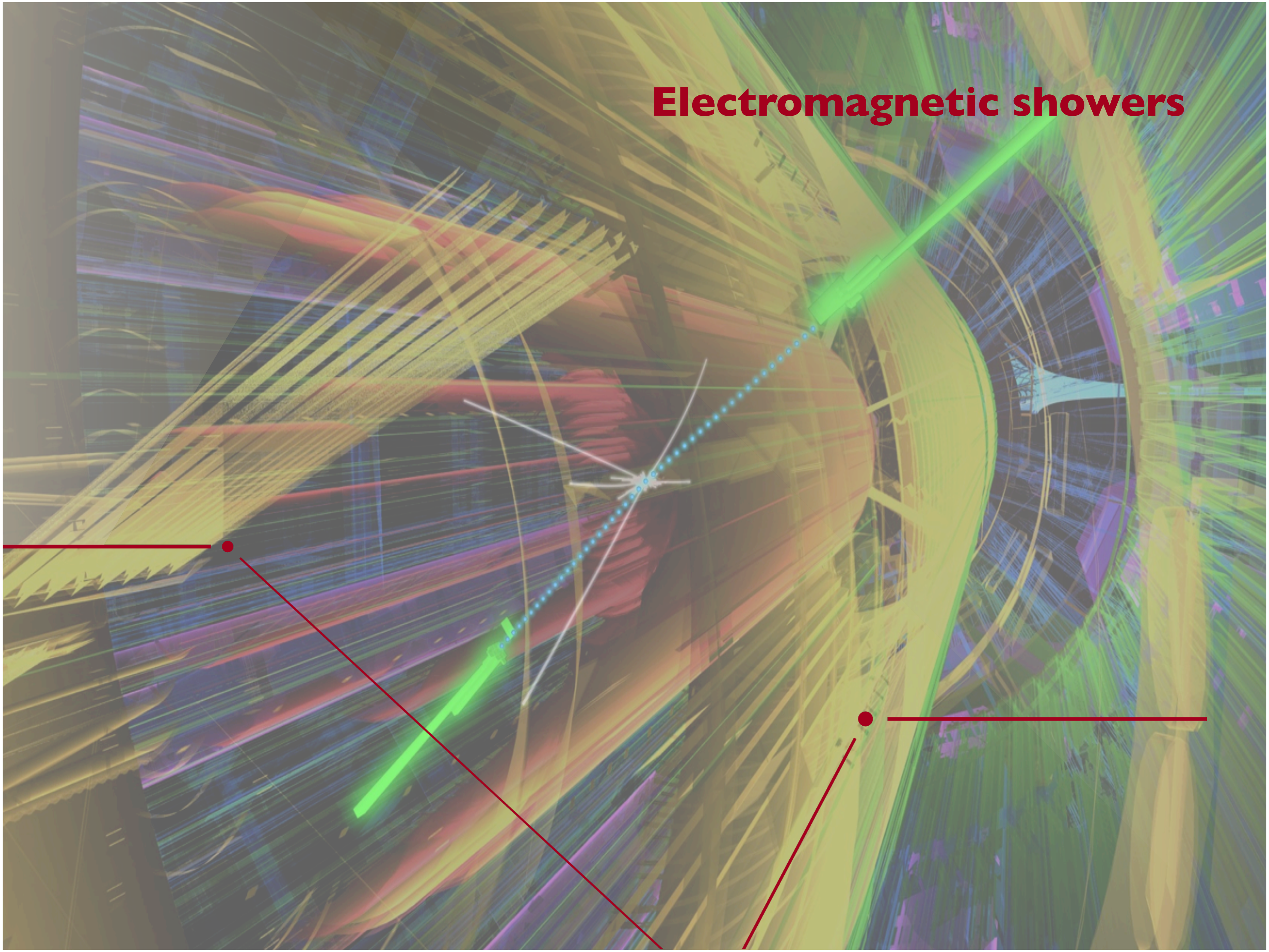
Outline

- **Electromagnetic** showers simulation
- **Hadronic** showers simulation
- Conclusions

Geant4 Validation portal (EM & HAD): http://www.geant4.org/geant4/results/results.shtml
LHC specific Physics Validation website: http://sftweb.cern.ch/validation/

Electromagnetic showers



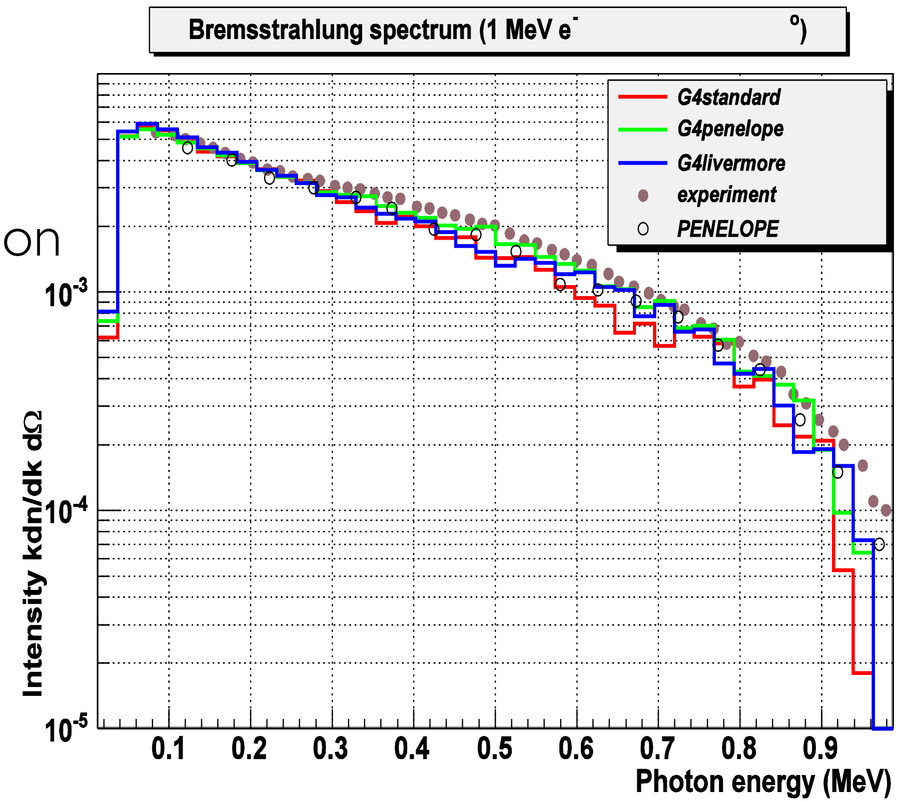
Recent improvements (versions 9.5 and 9.6)

- Physics modeling improvements:
  - Finalized unification of standard and low-energy packages
  - **Multiple and single scattering** models improvements
  - New default **Seltzer-Berger model for bremsstrahlung**
  - Relativistic LPM corrections for bremsstrahlung and gamma conversion
- Wentzel model is used for all **charged particles** (except $e^{\pm}$ below 100MeV and Opt3 builder)
  - Long Rutherford tail better described
  - Fix for very rare unphysical scattering angles for small step in low density materials (ATLAS report)
  - Best available model for trackers (LHCb requirement)

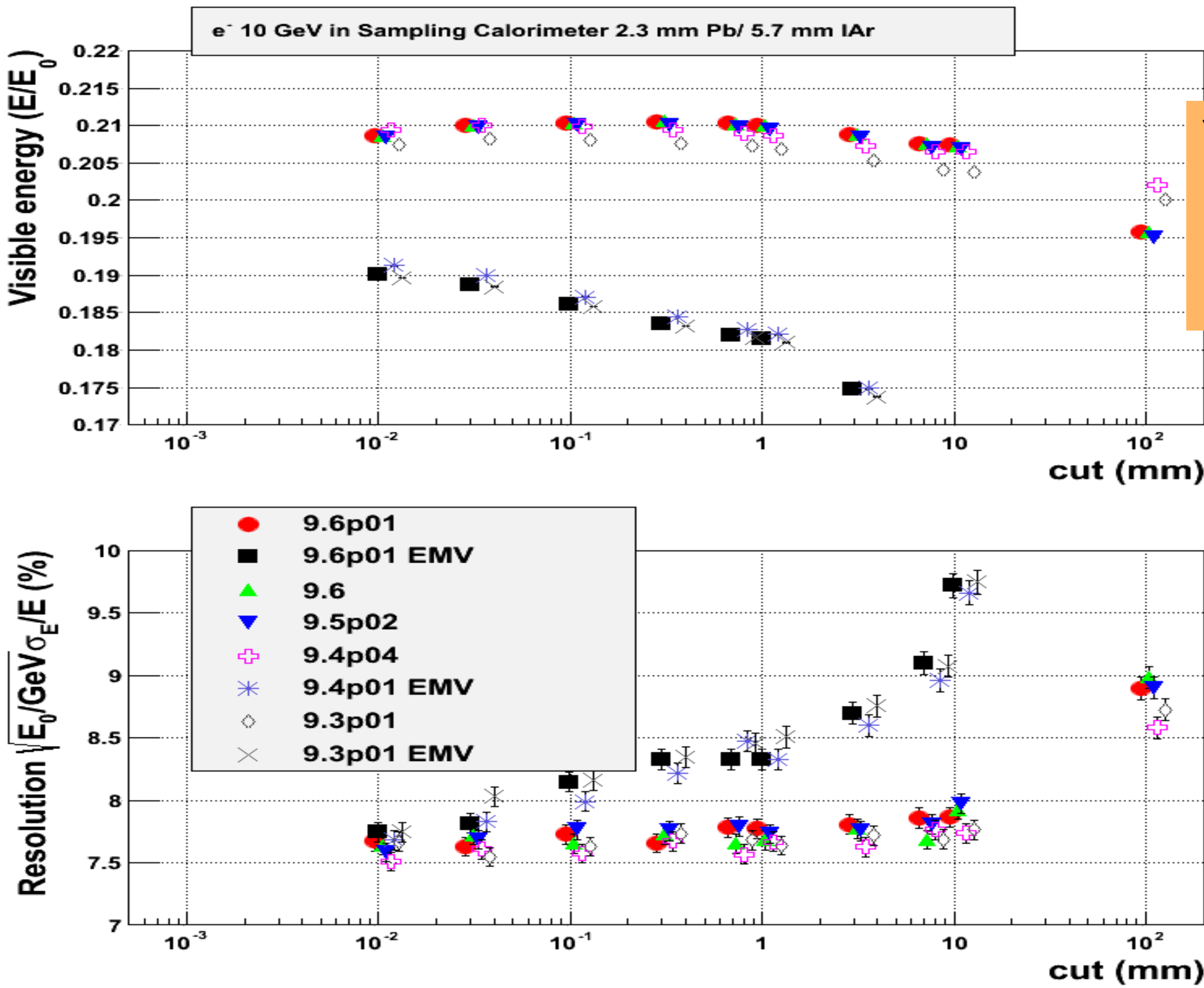
Recent EM related publications:
http://iopscience.iop.org/1742-6596/396/2/022013
http://iopscience.iop.org/1742-6596/331/3/032029
http://www.aesj.or.jp/publication/pnst002/data/898-903.pdf

Bremsstrahlung: Seltzer-Berger

- Increased number of interpolation points for $d\sigma/d\Omega$
- Updated screening functions
- Improved angular-distributions



Simplified Sampling Calorimeter Response (ATLAS barrel type)



Very Stable against Geant4 releases

Uniform results for cut < 1mm

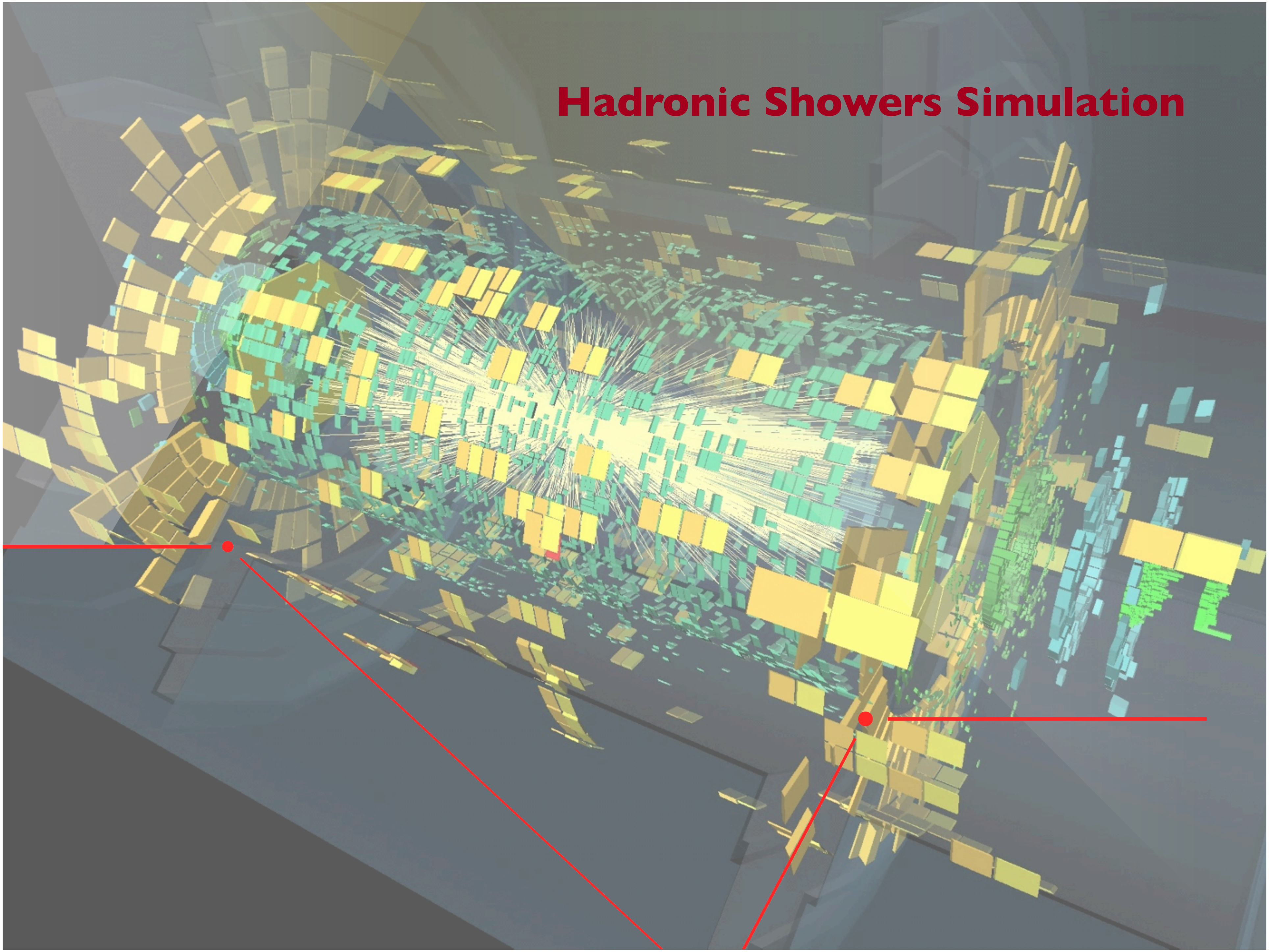
Geant4 9.6: EM Physics builders for HEP

EM models available for:

- γ, $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, p, $\Sigma^{\pm}$, Ξ^{-}, Ω^{-} , anti($\Sigma^{\pm}$, Ξ^{-}, Ω^{-})
- $\tau^{\pm}$, $B^{\pm}$, $D^{\pm}$, $D_s^{\pm}$, Λ_c^{+}, Σ_c^{+}, Σ_c^{++}, Ξ_c^{+} , anti(Λ_c^{+}, Σ_c^{+}, Σ_c^{++}, Ξ_c^{+})
- d, t, He3, He4, GenericIon, anti(d, t, He3, He4)

Constructor	Components	Comments
G4EmStandardPhysics	**Default** (QGSP_BERT, FTFP_BERT…)	ATLAS, and other HEP productions, other applications
G4EmStandardPhysics_option1	**Fast option** to simple step limitation, cuts used by photon processes (FTFP_BERT_EMV)	Similar to one used by CMS, good for crystals, not good for sampling calorimeters
G4EmStandardPhysics_option2	**Experimental**: updated photon models and bremsstrahlung on top of Opt1	Similar to one used by LHCb

Note: Non-HEP specific builders not shown


Hadronic Showers Simulation

Requirements

Geant4 is used by all LHC experiments

Requirements on hadronic models:

- precise description of showers in calorimeters
- precise description of interactions in thin-layers (trackers)

Description of hadronic showers in calorimeters

- Response (e/pi ratio): Jet-energy scale, systematic uncertainty
- Longitudinal: punch-through in muon systems, jet-calibration ("weighting" techniques), imaging calorimeters
- Lateral: cluster identification, particle-flow algorithms, jet-structure, imaging calorimeters
- Resolution: hadronic decay of W boson

Main hadronic models

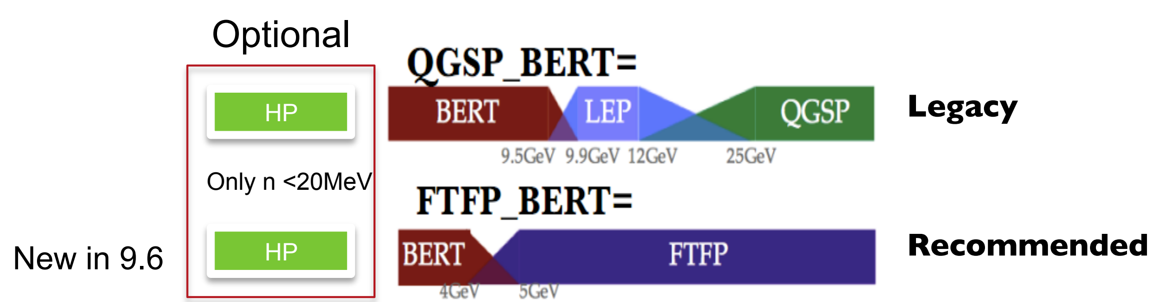
Developers' focus is on **few key models** covering energy range of LHC from MeV to TeV

Theory/Phenomenology based models:

- **String model** (>3GeV): Fritiof (FTF)
- **Intra-nuclear cascade** (<10GeV): Bertini Cascade (BERT)
- **Pre-compound/de-excitation** (<200MeV): Preco (P)

This combination gives best (simultaneous) description of:

- thin-target data (used for tuning)
- test-beams -mainly LHC, CALICE- (used for validation)
- LHC collision data



Response (pions)

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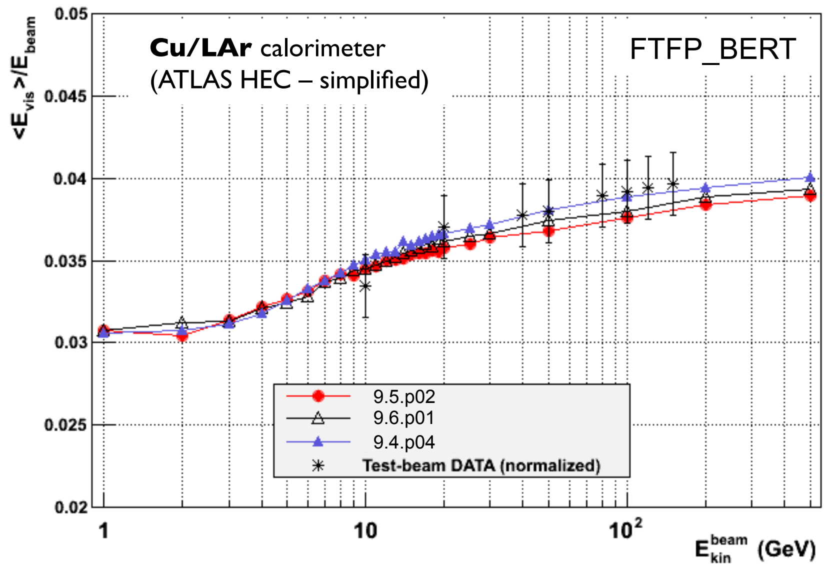
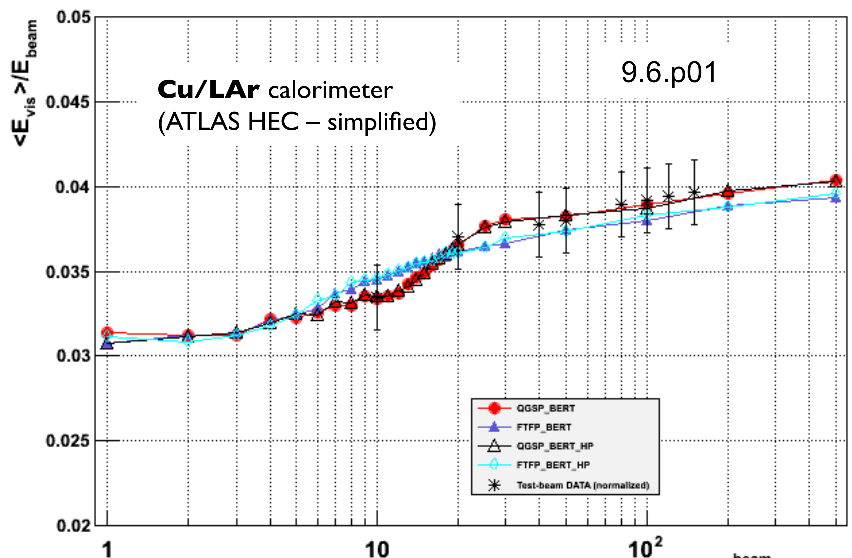
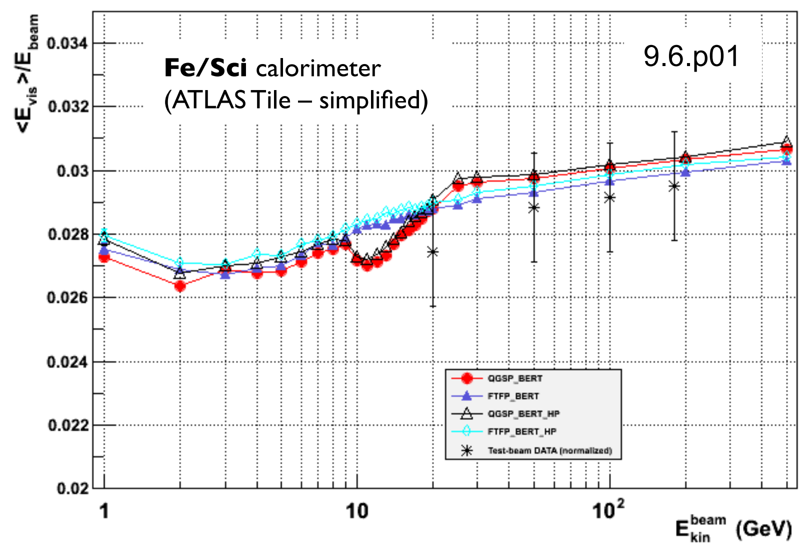


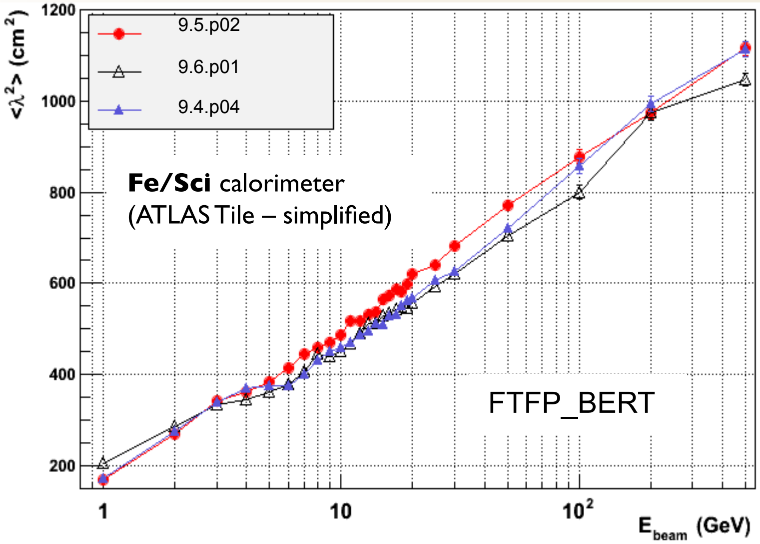
- Response **stable within <3%** (2010-2012)
- HP neutron does not effect response for light materials
- HP increases response on sci based calos

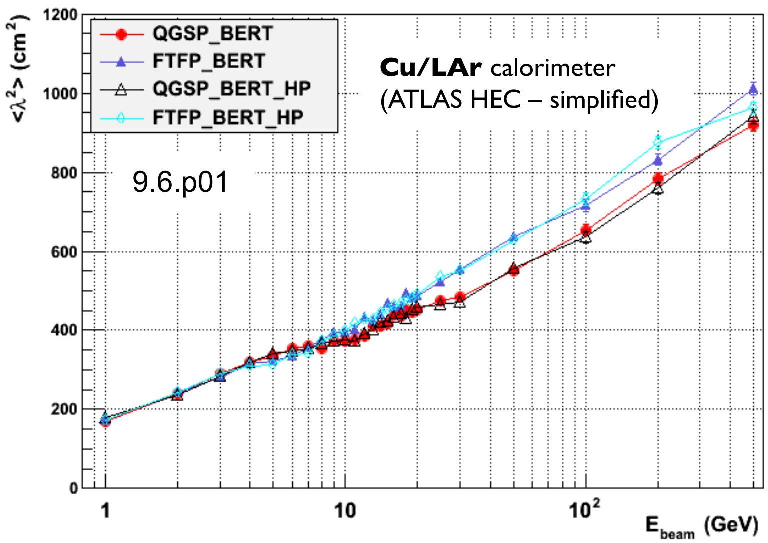




Data treatment described: 2011 IEEE Nuclear Science Symposium Conference Record ; 2128

Longitudinal development (pions)





- Hadronic shower length slightly reduced (~5%) in 9.6.p01
- No effect with HP (expected)
- Fritiof predicts longer showers w.r.t. QGS ("historical" G4 string model)
- **Further tuning of Fritiof ongoing**

- Note: LHC calorimeters granularity too coarse for detailed validation (collaboration w/ CALICE well established)

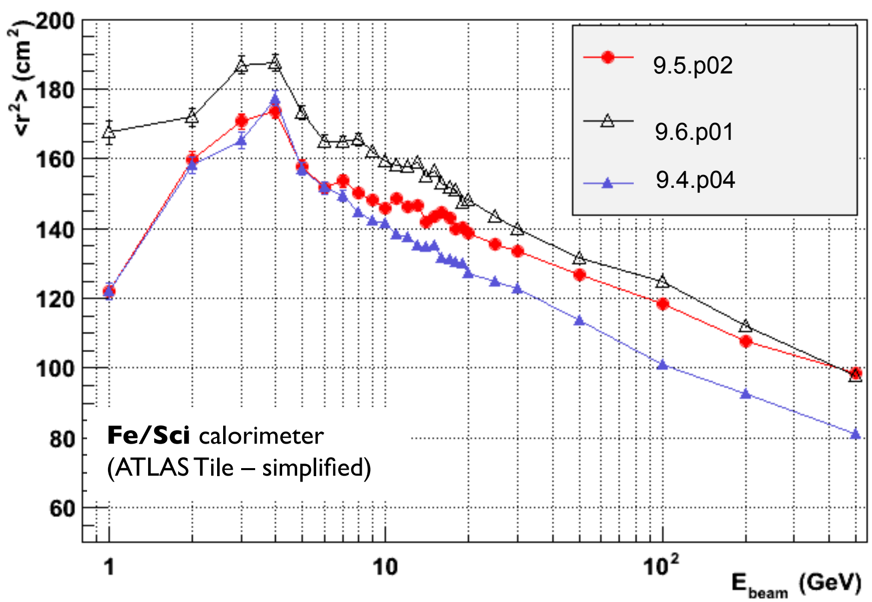
See talk from V. Uzhinskiy in this session for FTF update

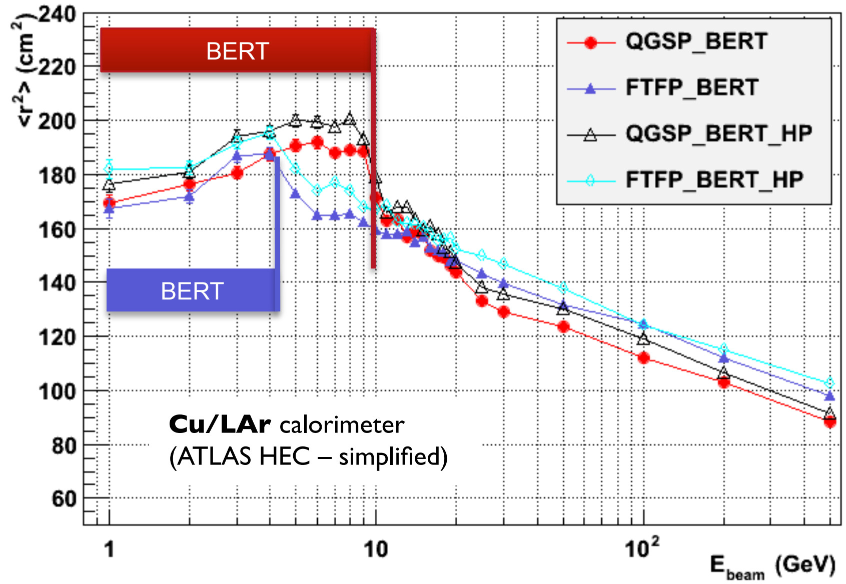
Data treatment described: 2011 IEEE Nuclear Science Symposium Conference Record ; 2128

Lateral development (pions)

- Latest G4 version predicts **wider showers** 10-15%
- Fundamental role of Bertini cascade
- **HP model further increases** shower width
- Note: QGSP_BERT wider 4-10 GeV (where BERT is used) in FTFP_BERT cascade code used up to 4 GeV. CALICE experimental data needed in this region

See talk from D.Wright in this session for BERT updates





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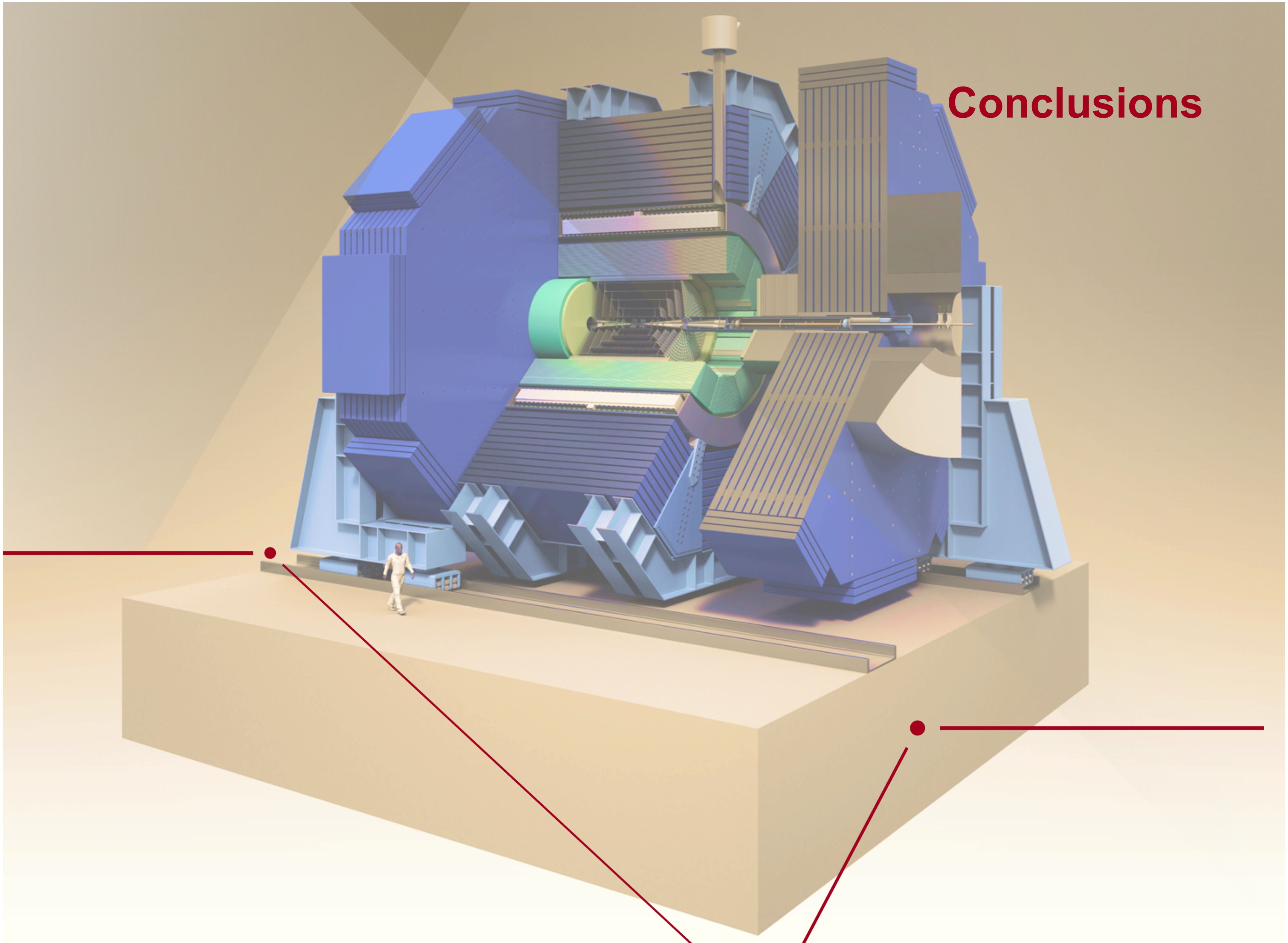
Conclusions



Status of Geant4 for calorimeters

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- **EM physics simulation reproduces results <1%**
  - However high precision LHC data show some additional work is needed to improve shower shape (lateral) description
  - Multiple Scattering is the challenging process for all MC simulation codes
    - Significant improvements achieved in latest G4 versions
    - Continuing effort to further improve and validate available models
- Hadronic physics considered satisfactory (precision <10%, shapes <20%):
  - Validation with LHC data shows Fritiof and Bertini are the "backbone" of G4 hadronics physics
  - **Response and resolution stable, in latest version longitudinal shapes slightly shorter, lateral showers larger**
  - Shower shapes: level of agreement probably ok for coarser LHC calorimeters, additional tuning for high granularity calorimeters
  - Increasing interest for HP (low-E neutrons) models for specific observables (lateral width, timing). Drawback: model with high CPU cost

Backup Slides

Additional Material

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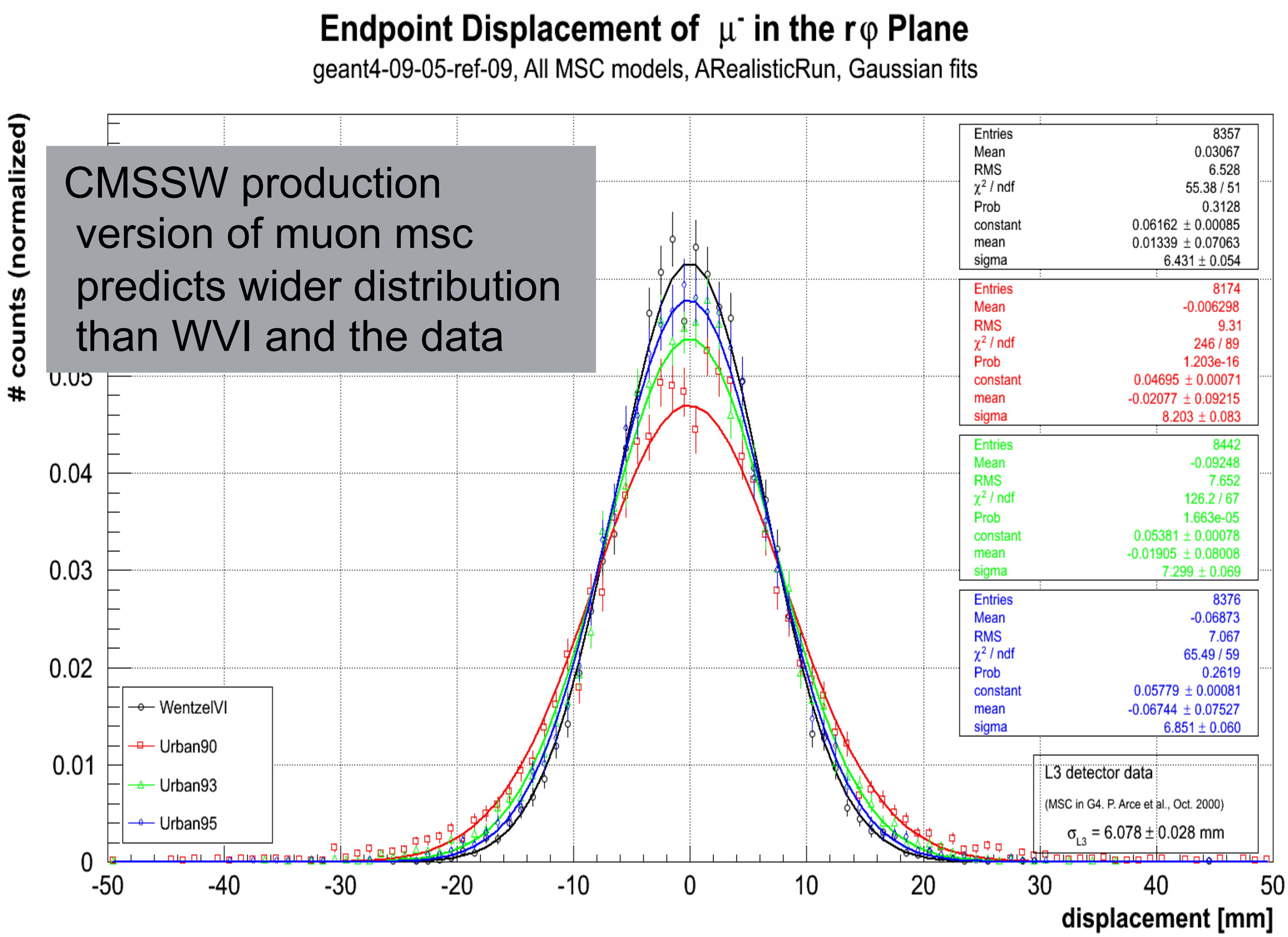
Geant4 muons versus L3 data (M.Schenk, CERN summer student)

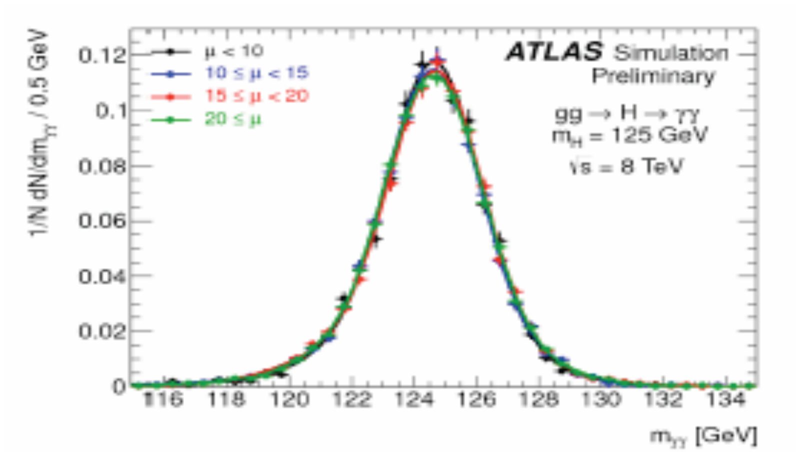


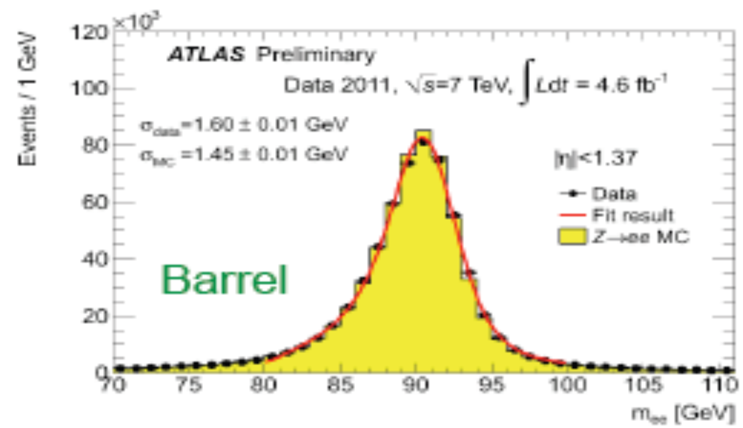
Di-photon mass resolution

Improved and pileup stable mass resolution by relying on calorimeter pointing for the photon direction measurement

Calorimeter resolution corrections derived from Z decay to electrons

- Add effective constant term to perfect MC resolutions through smearing
- 1% in barrel, 1.5 – 2.5% in endcap





Uncertainty on photon energy resolution (14 – 23%):

Sampling term (from test-beam), 'effective' constant term and e→γ extrapolation (material upstream calorimeter)

CMS Talk on Higgs

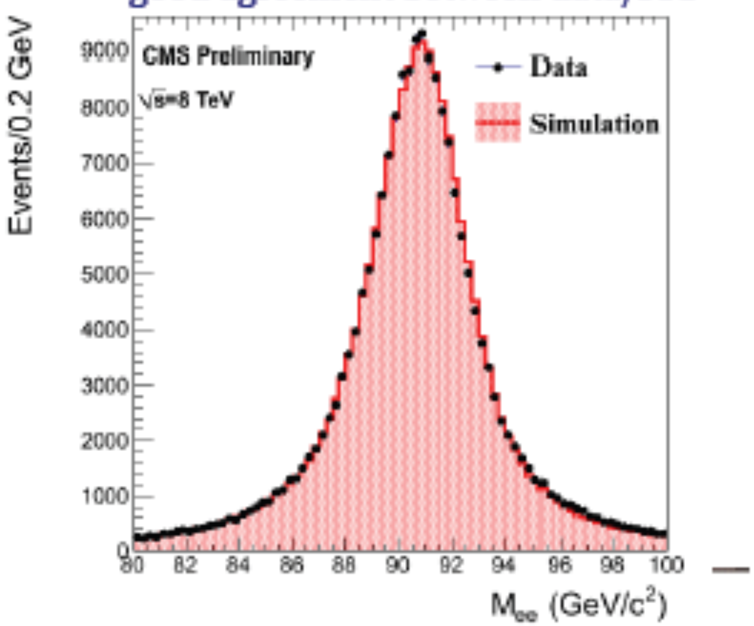
Ecal performance

$$m^2_{\gamma\gamma} = 2E_1E_2(1-\cos\alpha)$$

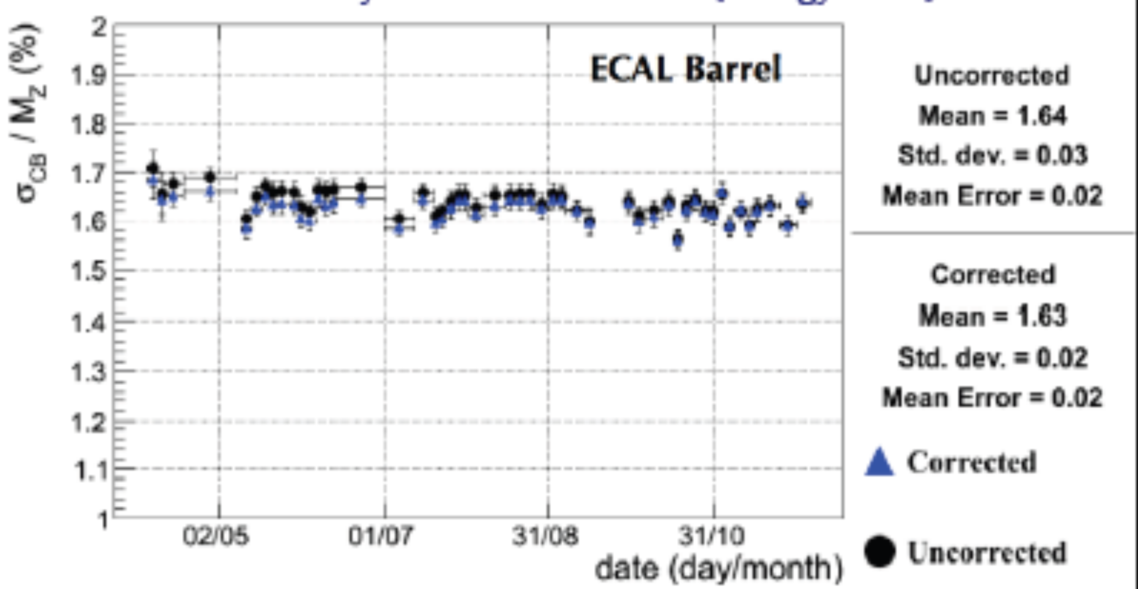
Energy resolution

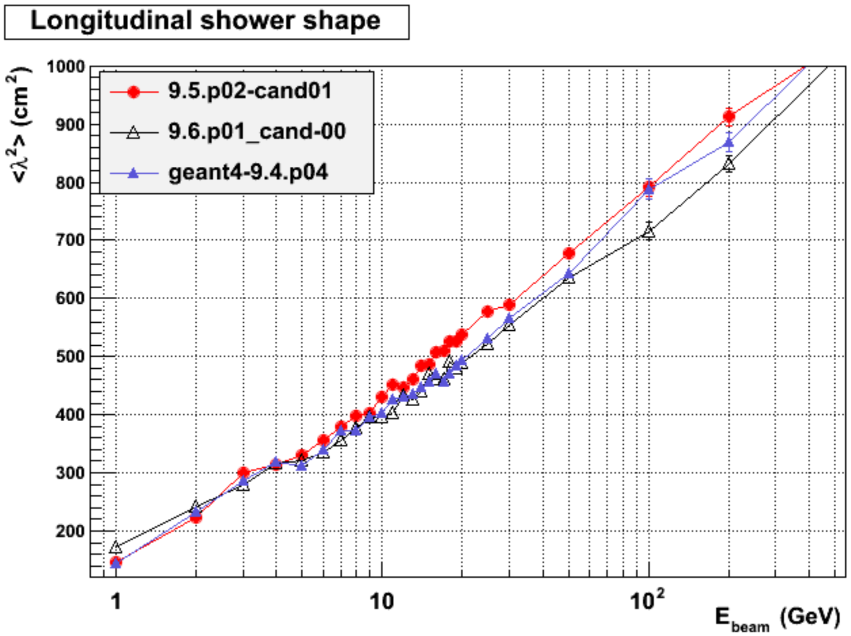
- **Very good ECAL performance in 2012**
  Z→ee mass resolution better than 1.2% for electrons with low bremsstrahlung in the barrel.
- **Stable performance** already using promptly reconstructed data

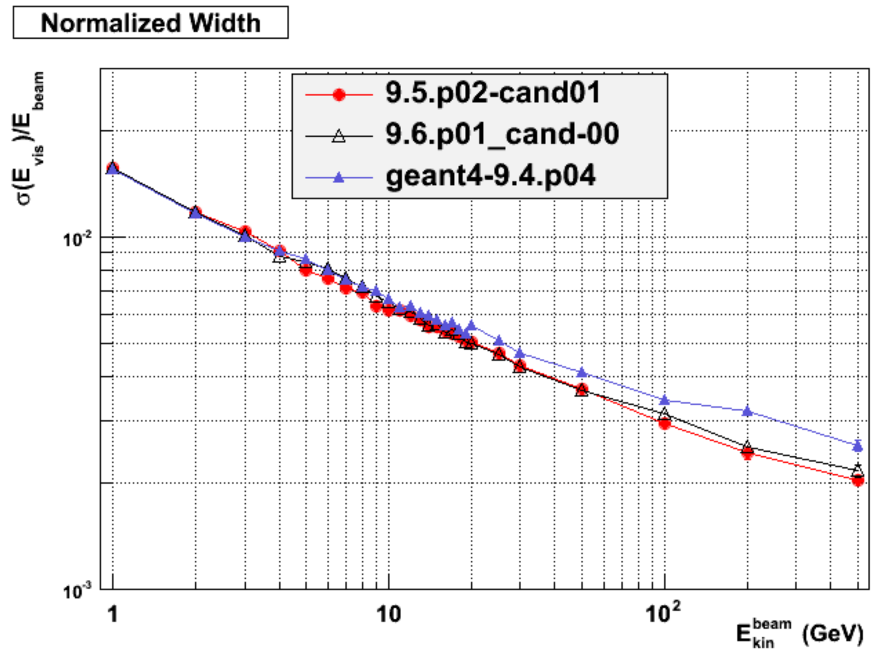
Z→ee lineshape:
good agreement between data/MC

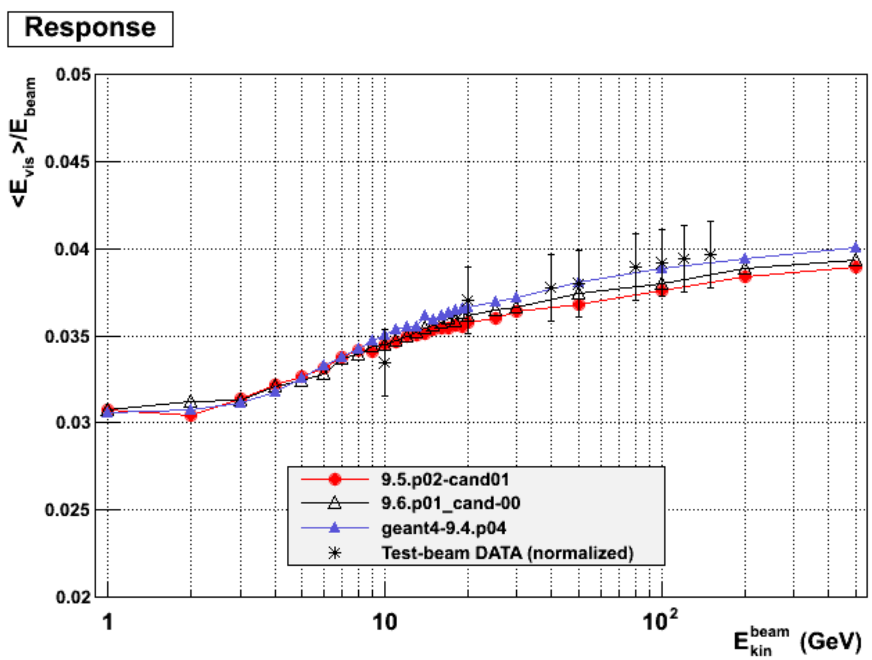


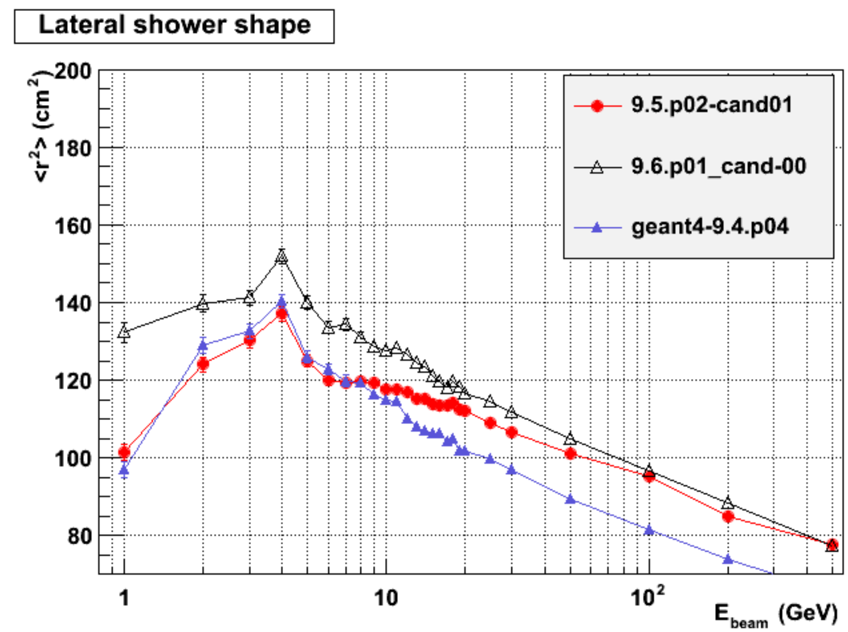
Z mass **resolution** as a function of time after application of analysis level corrections (energy scale)



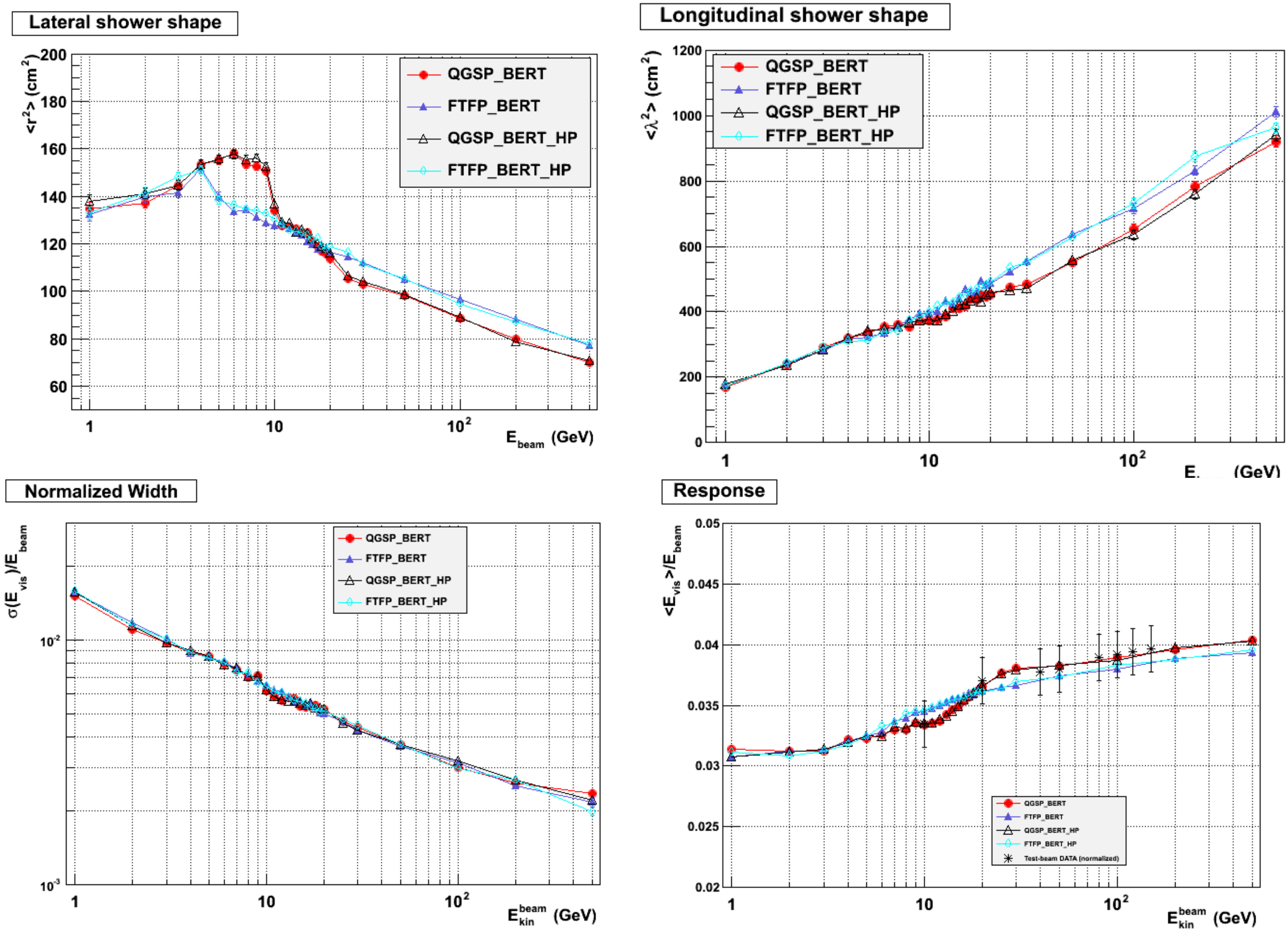




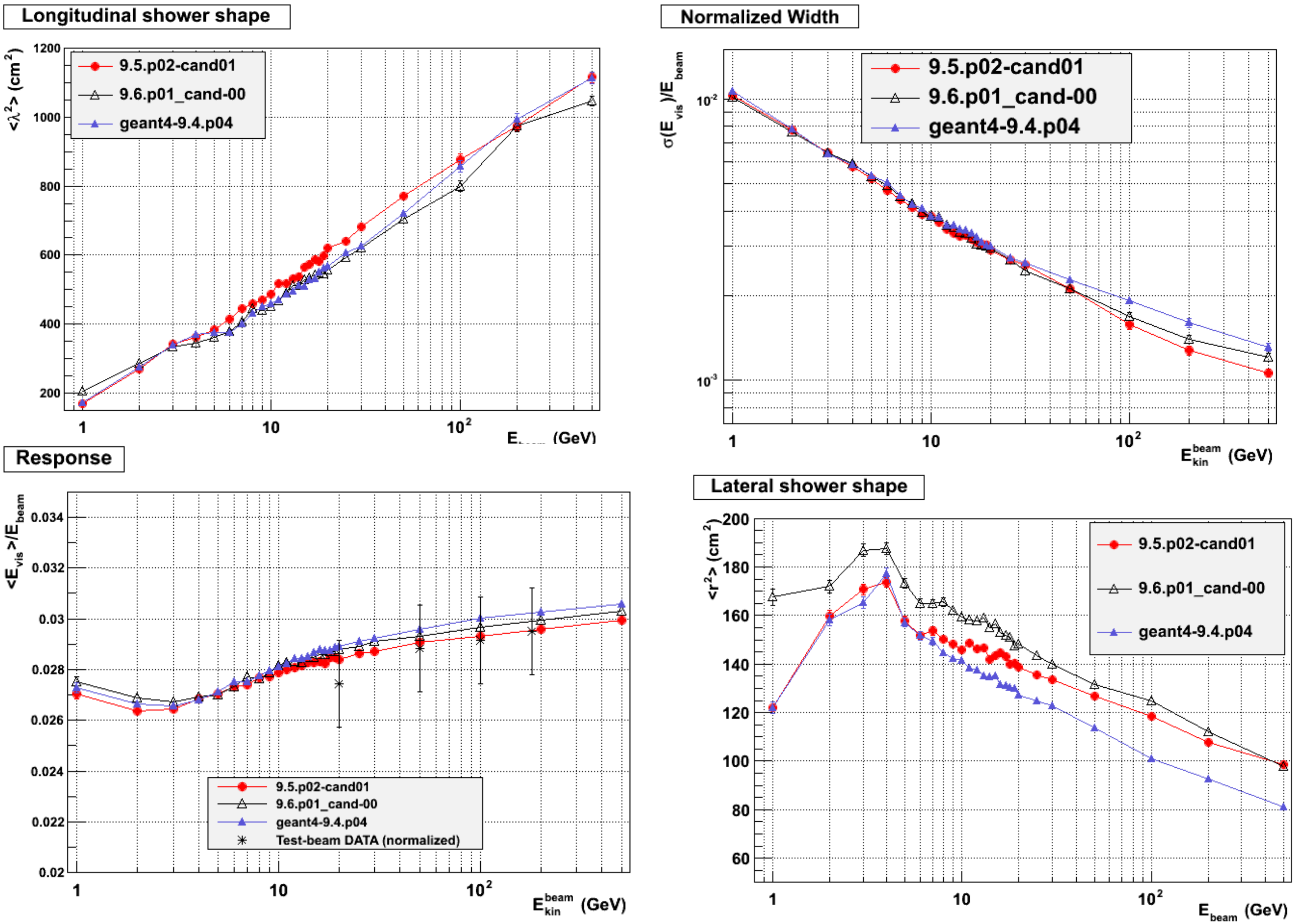




Cu/LAr FTF_BERT

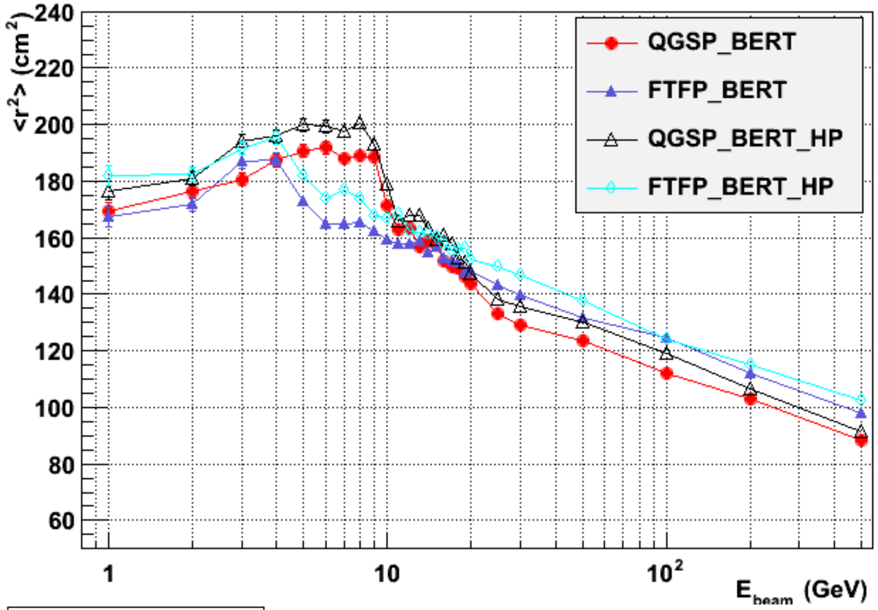

Lateral shower shape
<r2> (cm2)
Ebeam (GeV)
QGSP_BERT
FTFP_BERT
QGSP_BERT_HP
FTFP_BERT_HP
Longitudinal shower shape
<λ2> (cm2)
Normalized Width
σ(Evis)/Ebeam
Response
<Evis>/Ebeam
Ekin beam (GeV)
Test-beam DATA (normalized)

Cu/LAr 9.6.p01

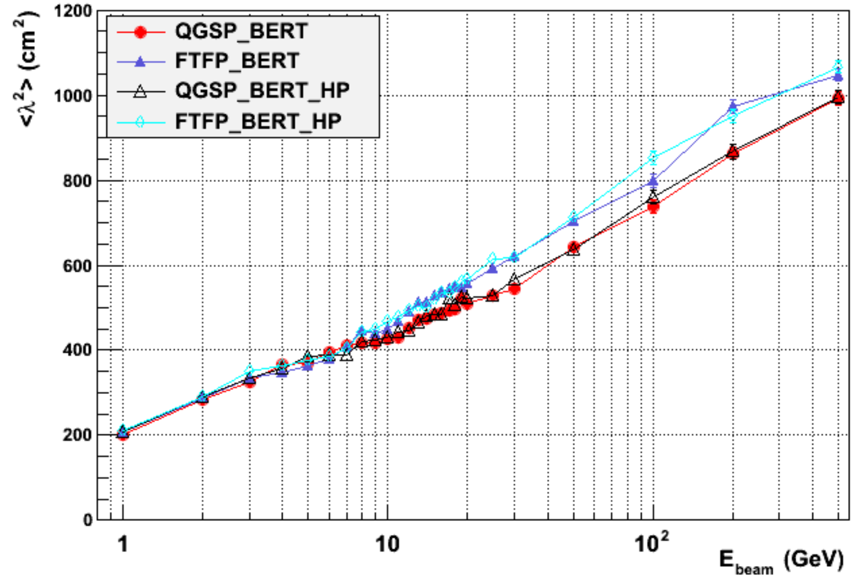


Fe/Sci FTFP_BERT

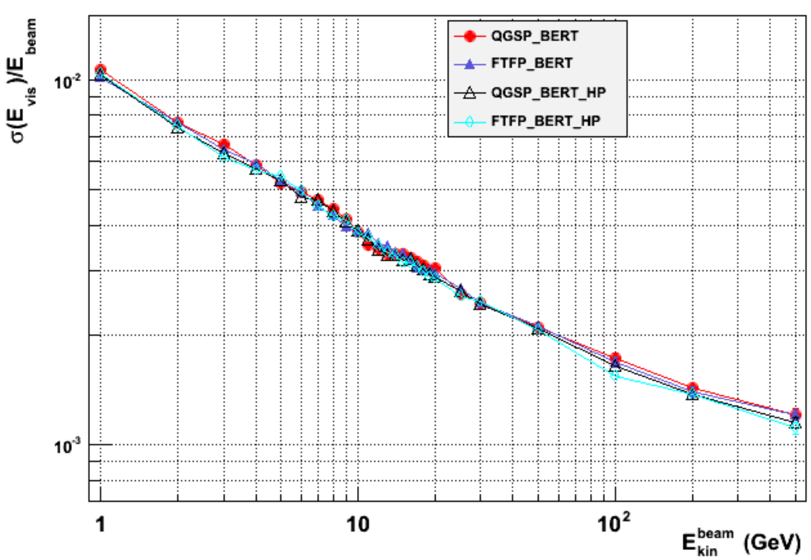
Lateral shower shape



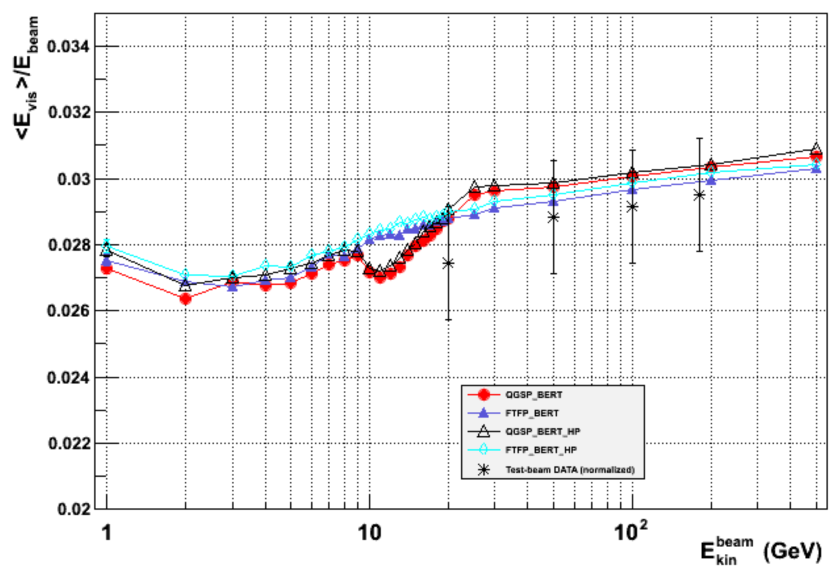
Longitudinal shower shape



Normalized Width



Response



Fe/Sci 9.6.p01

Study of radial profile

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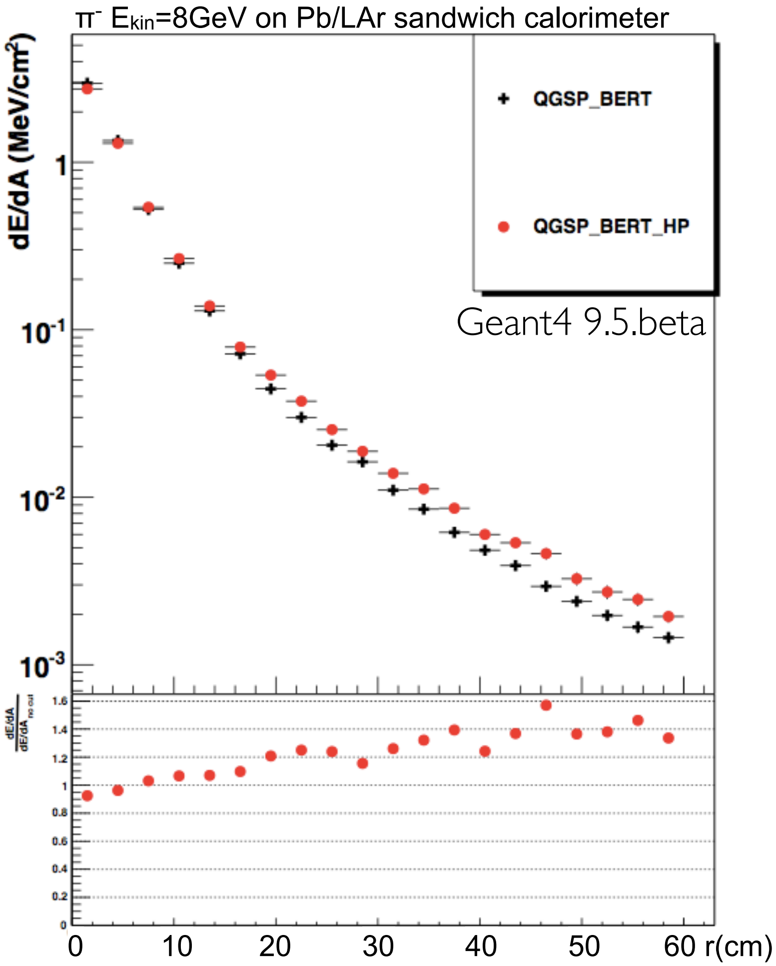
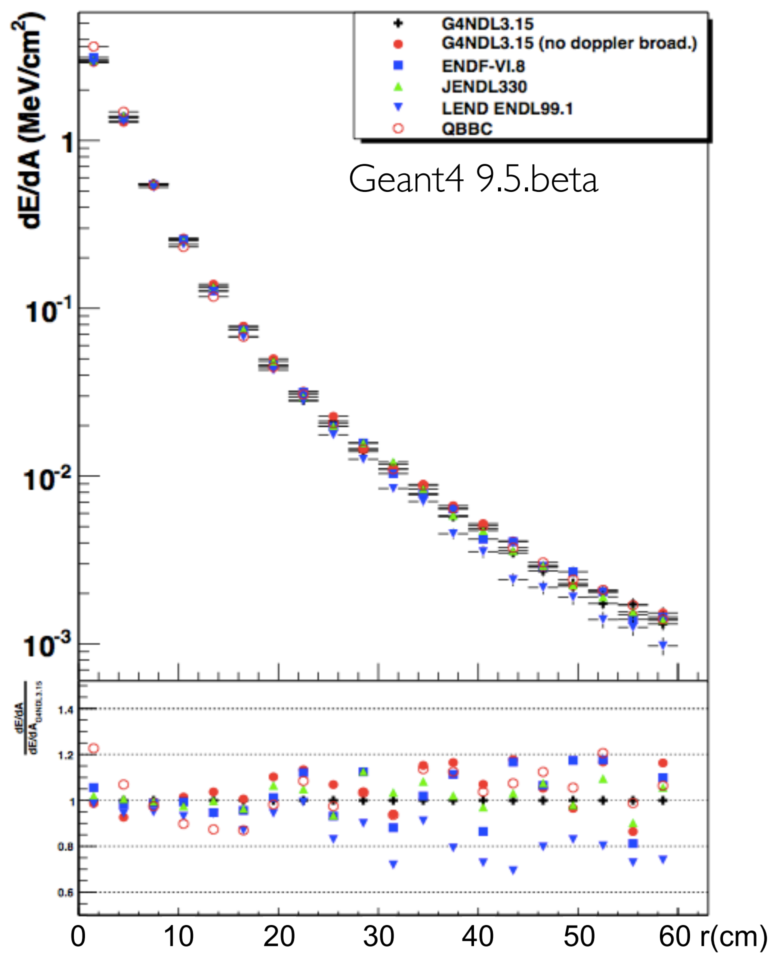
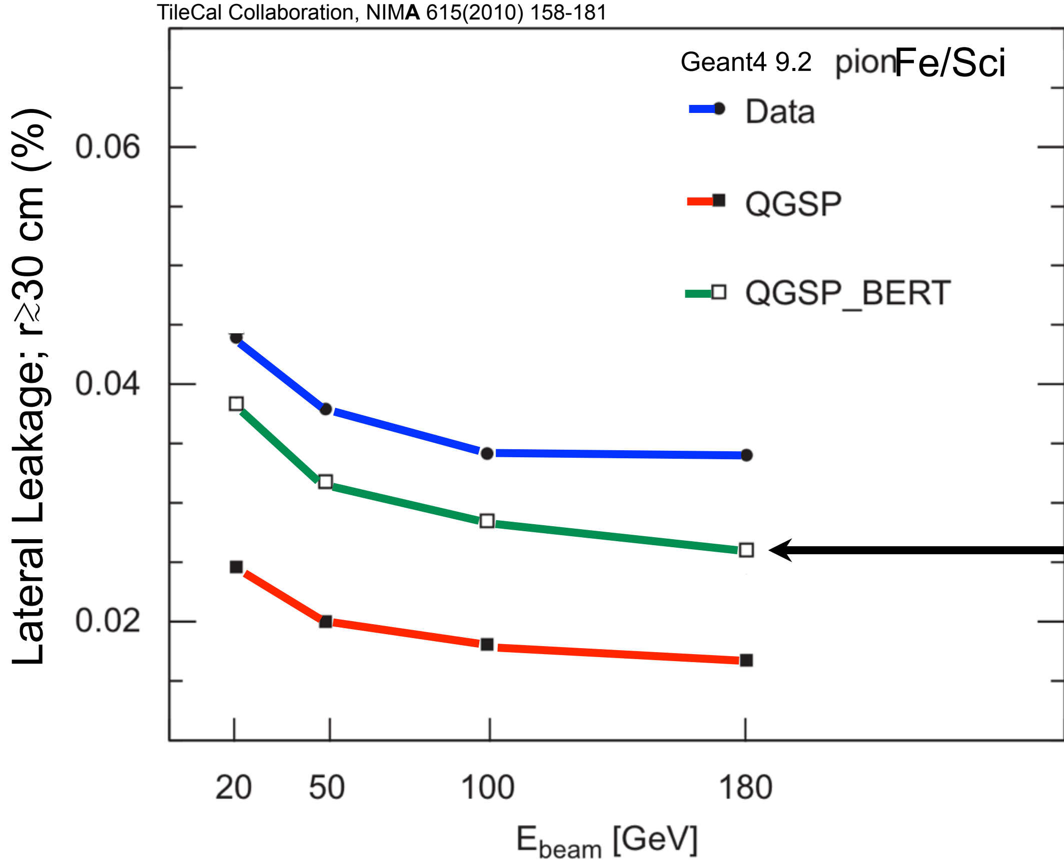


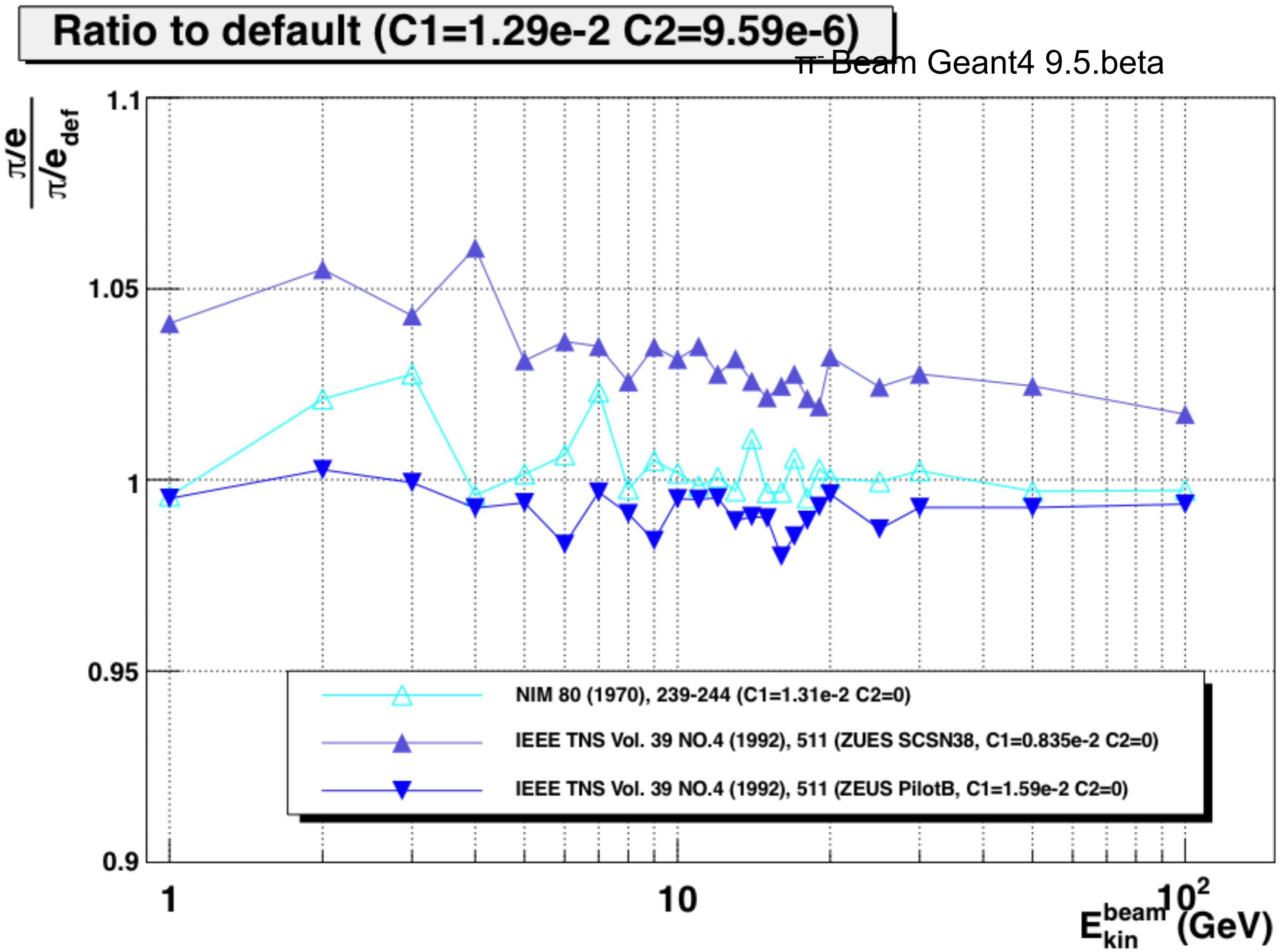


TileCal Collaboration, NIM**A** 615(2010) 158-181



Role of Cascade

Scintillator based calorimeters



Max 4% differences depending on Birks' parameters choice